Design of a 0.35 THz Extended Interaction Oscillator Based on Pseudospark-Sourced Sheet Electron Beam

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***Abstract*—A design of a 0.35 THz extended interaction oscillator (EIO) driven by pseudospark-sourced sheet electron beam is presented. PIC-3D simulations reveal that an output power of about 1.5 kW can be achieved when driven by a sheet electron beam with a voltage of 35 kV and a current density of 0.5 x 10^8 A/m^2 at 352 GHz.**

Keywords—extended interaction oscillator, pseudospark discharge, sheet electron beam, sub-terahertz.

I. Introduction

Compared with solid-state semiconductor devices, the vacuum electronic devices (VEDs) have higher output power at millimeter and sub-millimeter wavelengths, and hence vacuum electronic technology remains the main method to achieve kilowatt level power at high frequencies >100GHz [1, 2]. Nevertheless, when extending to sub-THz and THz frequencies, the radiation power of typical VEDs based on thermionic cathode electron beams is often greatly reduced due to the small beam current that can be transported through the device at a particular voltage. The limited beam current is mainly due to the restriction in the electron emission current density from the thermionic emitters. In VEDs high quality intense electron beams are required as the frequency increases. This has resulted in the pseudospark (PS) discharge attracting a lot of attention as a promising source of high quality, high intensity electron beam pulses as the beam current densities of up to 10^8 A m^{-2} and brightness up to 10^{12} A m^{-2} rad^{-2} have been reported [3-7]. A PS-sourced electron beam does not require the use of an external guide magnetic field as the beam is self-focused by ion channel focusing. This beam has a higher combined current density, charge per pulse and brightness compared to electron beams formed from any other known type of electron source making it an excellent cathode for compact millimeter-wave devices. In contrast to microwave VEDs based on conventional thermionic cathodes, the microwave radiation sources based on a PS discharge can generate a high current density beam that does not require an external magnetic field. As the frequencies move into the sub-terahertz and terahertz region, the size of device reduces greatly. This brings great difficulties and challenges with regard to the manufacture of the device. Therefore, a simplified structure is required, and when combined with an electron beam produced by a PS discharge a high power, high frequency, compact millimeter and sub-millimeter wave source is achievable.

Among various VEDs, the EIO as a linear beam vacuum device has gained considerable attention as a promising millimeter wave oscillator due to its high gain per unit length and compact configuration [8-11]. At millimeter-wave or THz frequencies, the achievable output power of the conventional O-type VEDs is limited greatly by the electron beam current. The emergence of the PS-sourced electron beam can overcome many of these limitations. The beam current can be further increased by adopting the sheet electron beam geometry due to the larger beam area. Simultaneously, when extending to THz frequencies, the conductor loss will increase greatly however the length of the EIO can be short, i.e. of the order of only a few wavelengths long, which mitigates the power loss as the frequency increases.

II. Design of the Interaction Circuit And Simulation

As shown in Fig. 1, the interaction circuit is composed of an eleven-slot resonant slow-wave structure (SWS) strongly coupled by symmetrical coupling cavities on both sides and an output structure. The generated electromagnetic (EM) wave in the resonant cavity is extracted through a waveguide attached to one of the coupled cavities with a coupling hole. Unlike the single gap cavity, the slow-wave resonant structure has multiple eigenmodes in the pass-band. Among these eigenmodes, the 2π mode is chosen as the operating mode maximizing the cavity impedance at the passband cut-offs for its maximum characteristic impedance.

To validate our design, the 3D PIC simulation code CST Particle Studio was employed to study the beam wave interaction of the planar EIO. The conductivity of the background material was set at $\sigma_{Cu}/5$ (σ_{Cu}=5.8 x 10^7 S/m). The RF circuit was driven by a high aspect ratio (8.3:1) PS-sourced sheet electron beam with a voltage of 35 kV and a current of 6 A (0.5 x 10^8 A/m^2 beam current density). As depicted in Fig. 2, many of the electrons have converted their kinetic energy to the electromagnetic radiation.

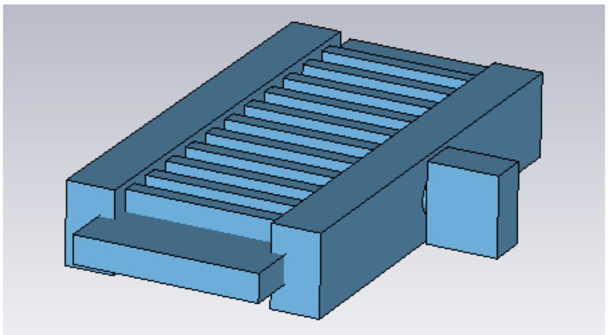

Fig. 1. Schematic of the EIO circuit.

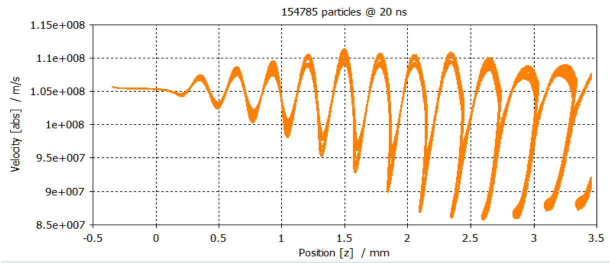

Fig. 2. The PIC phase space monitored at 20 ns.

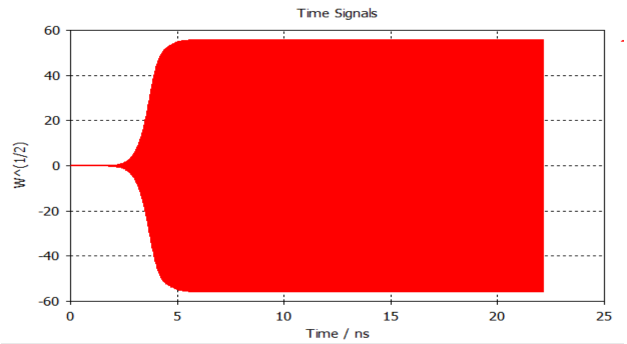

Fig. 3. The magnitude of the time-domain output signal.

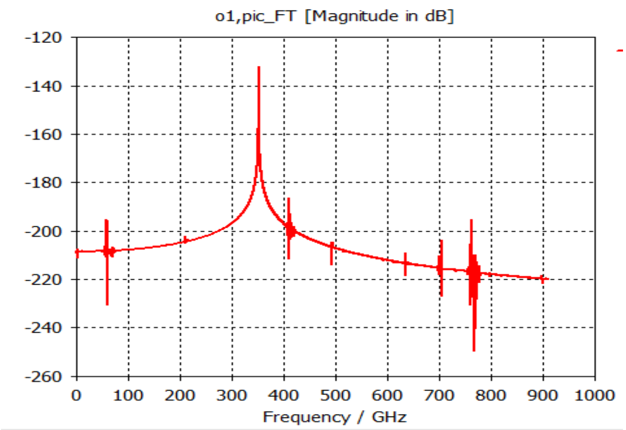

Fig. 4. The frequency spectrum of the output signal.

Fig.3 shows a plot of the instantaneous wave output power at a set location in the output structure versus time. Fig.4 shows the frequency spectrum produced from the fast Fourier transform (FFT) of the electric field. It is shown that the beam wave interaction has produced a radiation power of 1.5 kW and the output signal has a pure frequency spectrum. The center frequency mostly dominates at 352 GHz.

III. CONCLUSION

A sheet beam EIO has been designed to produce a radiation power of about 1.5 kW at around 352 GHz, as a sub-terahertz radiation source with high power that does not rely on an applied magnetic field. The simulation results have confirmed the proposed idea that it is feasible to combine the properties of a sheet electron beam generated by a PS discharge with that of planar EIO structures. It is a significant advance and may contribute to future development of planar VEDs. An experiment to investigate the generation of high power sub-millimeter-waves based on a PS-sourced sheet electron beam is currently being pursued at the University of Strathclyde.

ACKNOWLEDGMENT

The authors would like to thank the Engineering and Physical Sciences Research Council (EPSRC) UK for supporting this work, under Research Grant EP/S00968X/1. The China Scholarship Council, P.R. China, is gratefully acknowledged for the support of Jie Xie.

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